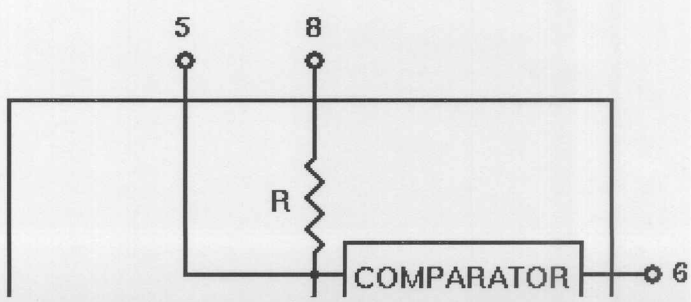
The 555 Timer IC

The 555 timer IC is an amazingly simple yet versatile device. It has been around now for many years and has been reworked into a number of different technologies. The two primary versions today are the original bipolar design and the more recent CMOS equivalent. These differences primarily affect the amount of power they require and their maximum frequency of operation; they are pin-compatible and functionally interchangeable.

This page contains only a description of the 555 timer IC itself. Functional circuits and a few of the very wide range of its possible applications will be covered in additional pages in this category.

The figure to the right shows the functional block diagram of the 555 timer IC. The IC is available in either an 8-pin round TO3-style can or an 8-pin mini-DIP package. In either case, the pin connections are as follows:



1. Ground.
2. Trigger input.
3. Output.
4. Reset input.
5. Control voltage.
6. Threshhold input.
7. Discharge.
8. $+V_{CC}$. +5 to +15 volts in normal use.

The operation of the 555 timer revolves around the three resistors that form a voltage divider across the power supply, and the two comparators connected to this voltage divider. The IC is quiescent so long as the trigger input (pin 2) remains at $+V_{CC}$ and the threshhold input (pin 6) is at ground. Assume the reset input (pin 4) is also at $+V_{CC}$ and therefore inactive, and that the control voltage input (pin 5) is unconnected. Under these conditions, the output (pin 3) is at ground and the discharge transistor (pin 7) is turned on, thus grounding whatever is connected to this pin.

The three resistors in the voltage divider all have the same value (5K in the bipolar version of this IC), so the comparator reference voltages are 1/3 and 2/3 of the supply voltage, whatever that may be. The control voltage input at pin 5 can directly affect this relationship, although most of the time this pin is unused.

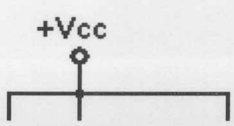
The internal flip-flop changes state when the trigger input at pin 2 is pulled down below $+V_{CC}/3$. When this occurs, the output (pin 3) changes state to $+V_{CC}$ and the discharge transistor (pin 7) is turned off. The trigger input can now return to $+V_{CC}$; it will not affect the state of the IC.

However, if the threshhold input (pin 6) is now raised above $(2/3)+V_{CC}$, the output will return to ground and the discharge transistor will be turned on again. When the threshhold input returns to ground, the IC will remain in this state, which was the original state when we started this analysis.

The easiest way to allow the threshhold voltage (pin 6) to gradually rise to $(2/3)+V_{CC}$ is to connect it to a capacitor being allowed to charge through a resistor. In this way we can adjust the R and C values for almost any time interval we might want.

The 555 can operate in either monostable or astable mode, depending on the connections to and the arrangement of the external components. Thus, it can either produce a single pulse when triggered, or it can produce a continuous pulse train as long as it remains powered.

In monostable mode, the timing interval, t, is set by a single resistor and capacitor, as shown to the right. Both the



threshhold input and the discharge transistor (pins 6 & 7) are connected directly to the capacitor, while the trigger input is held at $+V_{CC}$ through a resistor. In the absence of any input, the output at pin 3 remains low and the discharge transistor prevents capacitor C from charging.

When an input pulse arrives, it is capacitively coupled to pin 2, the trigger input. The pulse can be either polarity; its falling edge will trigger the 555. At this point, the output rises to $+V_{CC}$ and the discharge transistor turns off. Capacitor C charges through R towards $+V_{CC}$. During this interval, additional pulses received at pin 2 will have no effect on circuit operation.

The standard equation for a charging capacitor applies here: $e = E(1 - \varepsilon^{(-t/RC)})$. Here, "e" is the capacitor voltage at some instant in time, "E" is the supply voltage, V_{CC}, and "ε" is the base for natural logarithms, approximately 2.718. The value "t" denotes the time that has passed, in seconds, since the capacitor started charging.

We already know that the capacitor will charge until its voltage reaches $(2/3)+V_{CC}$, whatever that voltage may be. This doesn't give us absolute values for "e" or "E," but it does give us the ratio e/E = 2/3. We can use this to compute the time, t, required to charge capacitor C to the voltage that will activate the threshhold comparator:

$$2/3 = 1 - \varepsilon^{(-t/RC)}$$

$$-1/3 = -\varepsilon^{(-t/RC)}$$

$$1/3 = \varepsilon^{(-t/RC)}$$

$$\ln(1/3) = -t/RC$$

$$-1.0986123 = -t/RC$$

$$t = 1.0986123RC$$

$$t = 1.1RC$$

The value of 1.1RC isn't exactly precise, of course, but the roundoff error amounts to about 0.126%, which is much closer than component tolerances in practical circuits, and is very easy to use. The values of R and C must be given in Ohms and Farads, respectively, and the time will be in seconds. You can scale the values as needed and appropriate for your application, provided you keep proper track of your powers of 10. For example, if you specify R in megohms and C in microfarads, t will still be in seconds. But if you specify R in kilohms and C in microfarads, t will be in milliseconds. It's not difficult to keep track of this, but you must be sure to do it accurately in order to correctly calculate the component values you need for any given time interval.

The timing interval is completed when the capacitor voltage reaches the $(2/3)+V_{CC}$ upper threshhold as monitored at pin 6. When this threshhold voltage is reached, the output at pin 3 goes low again, the discharge capacitor (pin 7) is turned on, and the capacitor rapidly discharges back to ground once more. The circuit is now ready to be triggered once again.

If we rearrange the circuit slightly so that both the trigger and threshhold inputs are controlled by the capacitor voltage, we can cause the 555 to trigger itself repeatedly. In this case, we need two resistors in the capacitor charging path so that one of them can also be in the capacitor discharge path. This gives us the circuit shown to the left.

In this mode, the initial pulse when power is first applied is a bit longer than the others, having a duration of 1.1(Ra + Rb)C. However, from then on, the capacitor alternately charges and discharges between the two comparator threshhold voltages. When charging, C starts at $(1/3)V_{CC}$ and charges towards V_{CC}. However, it is interrupted exactly halfway there, at $(2/3) V_{CC}$. Therefore, the charging time, t1, is -ln(1/2)(Ra + Rb)C = 0.693(Ra + Rb)C.

When the capacitor voltage reaches $(2/3)V_{CC}$, the discharge transistor is enabled (pin 7), and this point in the circuit becomes grounded. Capacitor C now discharges through Rb alone. Starting at $(2/3)V_{CC}$, it discharges towards ground, but again is interrupted halfway there, at $(1/3)V_{CC}$. The discharge time, t2, then, is -ln(1/2)(Rb)C = 0.693(Rb)C.

The total period of the pulse train is t1 + t2, or 0.693(Ra + 2Rb)C. The output frequency of this circuit is the inverse of the period, or 1.44/(Ra + 2Rb)C.

Note that the duty cycle of the 555 timer circuit in astable mode cannot reach 50%. On time must always be longer than off time, because Ra must have a resistance value greater than zero to prevent the discharge transistor from directly shorting V_{CC} to ground. Such an action would immediately destroy the 555 IC.

One interesting and very useful feature of the 555 timer in either mode is that the timing interval for either charge or discharge is independent of the supply voltage, V_{CC}. This is because the same V_{CC} is used both as the charging voltage and as the basis of the reference voltages for the two comparators inside the 555. Thus, the timing equations above depend only on the values for R and C in either operating mode.

In addition, since all three of the internal resistors used to make up the reference voltage divider are manufactured next to each other on the same chip at the same time, they are as nearly identical as can be. Therefore, changes in temperature will also have very little effect on the timing intervals, provided the external components are temperature stable. A typical commercial 555 timer will show a drift of 50 parts per million per Centigrade degree of temperature change (50 ppm/°C) and 0.01%/Volt change in V_{CC}. This is negligible in most practical applications.
